Toward the risk assessment of ship navigation in Arctic Sea Route under decreasing ice condition

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Outline

• Background and motivation
• How to assess the risk of collision
• An example case
• Conclusions and future perspective
Background

- Arctic Sea Route (Northern Sea Route and North West Passage) has become increasingly available.
- Independently floating ice (multi-year ice, icebergs and bergy bits) are increasing along the route. They increase the risk of ship collision with an ice floe.
Background: energy based estimation of collision force

• Basis for IACS URI
• A part of ship’s kinetic energy is expended in crushing.
• \( M_e \): effective mass; \( M_e = \frac{M_{\text{ship}}}{\text{mass reduction factor}} \)
• Mass and motion of the ice are not considered.
• Is it applicable to collision with a small ice piece?
Objective of this study

Propose a new method to estimate ice collision force for a small ice piece.

- Effective kinetic energy is replaced with a simple and straightforward estimation of energy consumption.
Outline

• Background and motivation

• How to assess the risk of collision
  – Ice type and size
  – Velocity of the ice before collision
  – Kinetic energy consumed by the collision
  – Maximum load on the ship hull

• An example case

• Conclusions and future perspective
Ice type and size

• A bergy bit is assumed because it is difficult to detect this kind of ice with a ship’s radar.

• Typical size of bergy bits: 10 to 15 m

"Bergy bit"
Photo by adactio / CC BY 2.5
Motion of a bergy bit before collision

- Ice moves by waves propagated from the ship.
- The velocity of the ice piece is estimated as a linear function of the ship speed:
  \[ \mathbf{v_{\text{i}}} = \alpha \mathbf{v_{\text{s}}} \]
Estimation of $\alpha$

- Model ship speed: 0.5 m/s
- $\alpha \approx 0.2$ ???
Velocity after collision

- The velocity of the ship and ice after collision is estimated using momentum conservation theory.

\[ m_{\text{sl}} v_{\text{sl}} + m_{\text{i}} v_{\text{i}} = (m_{\text{sl}} + m_{\text{i}}) v \]

\[ v = \frac{m_{\text{sl}} v_{\text{sl}} + m_{\text{i}} v_{\text{i}}}{m_{\text{sl}} + m_{\text{i}}} \]

- Simple heads-on collision is assumed at this time.
Energy consumption

• Kinetic energy consumed by the collision is estimated using the velocities before and after collision.

\[ \Delta E = \frac{1}{2} m_{\downarrow s} v_{\downarrow s} \uparrow 2 + \frac{1}{2} m_{\downarrow i} v_{\downarrow i} \uparrow 2 - \frac{1}{2} (m_{\downarrow s} + m_{\downarrow i}) v_{\uparrow 2} = \frac{1}{2} m_{\downarrow s} v_{\downarrow s} \uparrow 2 + \frac{1}{2} m_{\downarrow i} v_{\downarrow i} \uparrow 2 - \frac{1}{2} (m_{\downarrow s} + m_{\downarrow i}) (m_{\downarrow s} v_{\downarrow s} + m_{\downarrow i} v_{\downarrow i}) / (m_{\downarrow s} + m_{\downarrow i}) \uparrow 2 \]
Maximum load on the hull

• The method to estimate the load on the ship hull from energy consumption is borrowed from Daley and Kim (2010).

\[ F_{\downarrow n} = P_{\downarrow 0} f_{\downarrow a} \uparrow (1 + ex) (\Delta E(d(1+ex)+1)/P_{\downarrow 0} f_{\downarrow a} \uparrow (1+ex)) \uparrow d(1+ex)/d(1+ex) + 1 \]
Outline

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An example scenario

• A head-on collision of a ship with a bergy bit.

• The shape of the ice is assumed nearly spherical, but the contact edge of the ice is assumed pyramidal.
# Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>value</th>
<th>unit</th>
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<tbody>
<tr>
<td>Mass of the ship</td>
<td>$M$</td>
<td>150</td>
</tr>
<tr>
<td>Ice pressure term</td>
<td>$P_0$</td>
<td>3.0</td>
</tr>
<tr>
<td>Exponent on pressure-area function</td>
<td>$ex$</td>
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<tr>
<td>Pyramidal angle</td>
<td>$\phi$</td>
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<td>Representative length of the ice</td>
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<td>15</td>
</tr>
<tr>
<td>Density of the ice</td>
<td>$\rho$</td>
<td>900</td>
</tr>
</tbody>
</table>

- Variables: ship speed (0 to 10 kts) and $\alpha$ (0, 0.2, 0.5)

\[ v\downarrow l = \alpha v \downarrow s \]
Results: energy consumption

- Effect of $\alpha$ is significant.

\[ v_{\downarrow i} = \alpha v_{\downarrow s} \]
Results: max. normal force

- Limit speed in Daley and Kim (2010): 2.5 m/s
Discussion 1/2

• The present method uses momentum conservation theory so that the calculation of energy consumption is straightforward.

• The method is an idea suitable for investigation of the collision of a ship and an ice floe, and thus a method suitable for assessing the safety of navigation in decreasing ice condition.
Discussion 2/2: issues

• Examination of the ice velocity before a collision is insufficient.
• The method should be extended so that an oblique collision to a ship bow can be treated.
• The deformation of a ship is not taken into consideration in the present study.
Outline

• Background and motivation
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• Conclusions and future perspective
Conclusions and future perspective

• The scenario of ship collision with a small ice floe at the normal, open-water navigation speed is examined, and the new method of evaluating a maximum normal force is proposed.

• The maximum force as a result of an analysis becomes an appropriate magnitude.

• Consideration of an oblique collision and other issues are required for further investigation.
Acknowledgments

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Thank you for your attention!
Model ship and Synthetic ice

Synthetic ice
- Made of polyolefin
  - 150 mm × 150 mm × 60 mm
- Density: 902 kg/m³
  (Close to that of the sea ice)
Restriction of motion of the synthetic ice

Motion of the ice piece is restricted to surging, swaying and pitching.

Model ship

A pair of strings

A pair of cylindrical rods

Water Surface

Water Surface

Water Surface
Improvement from previous study

**Experiment**
- a new camera to take ice motions in 240 frames per second.
- markers on the ship and ice; we measured the distance of these markers to decide the instant of collision.
- stainless rods are replaced with strings to restrict ice motion. (will be explained later)

**Simulation**
- Ship velocity of simulation fits that of experiments to suppress starting wave.
- Reflection of wave from the surrounding walls is damped.
Movie of experiment

Underwater view

Ship velocity: 0.5m/s

a slow-motion replay: x 1/8
The velocity oscillates in the experiment.

We divide the motion to the two parts.

- The earlier part represents the effect of experimental situations and is not essential.
- The latter part represents the indirect effect of the ship through the water before collision.
Numerical simulation

- We use the STAR-CCM+ v9

1. Overset method
   - used to represent motion of objects.
2. VOF method
   - Free surface is considered.
3. DFBI (Dynamic Fluid Body Interaction)
   - DFBI realizes motion of the ice.
Estimation of $\alpha$ by small scale model test

Estimation of $\alpha$ by numerical simulation

3-D simulation with Star-CCM + v8 and v9

VOF of water at the central section of the computational domain

Ice motion before collision

Ice velocity before collision

- Model ship speed: 0.5 m/s
- $\alpha = 0.2$
Discussion

- Ice velocities before collision in the simulation and in the experiment agreed well each other.
- The simulation produces a good estimation of the relative velocity of the ice against the ship immediately before the collision.
発表メモ

• 発表時間：20分
• 15分ぐらいしゃべる？